

## DEMONSTRATION OF AN ENGINEERED MICROTIDAL WETLAND: An Alternative Waterfowl Management Strategy for Suisun Marsh

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*Abstract:* We propose a microtidal wetland management system as an alternative to non-tidal seasonal wetland management for preferred waterfowl game species in Suisun Marsh. New wetlands will be permanently flooded, with a rim of stable brackish high marsh. Native submerged aquatic species (*Potamogeton pectinatus*, *Ruppia maritima*), rather than a mix of non-native and native emergent species, would dominate the vegetation. This habitat type conversion should not reduce the most important underlying functions and values of seasonal wetlands in this subregion, which is to provide extensive, high-quality waterfowl habitat, and substantial support to other wildlife species. The basic purpose of the management strategy is to equal or exceed the antecedent seasonal wetland management in all these aspects, and provide new benefits to fish and other wildlife where there were previously, in some cases, adverse effects.

### INTRODUCTION

The goal of microtidal wetland waterfowl management is to provide extensive, high quality-waterfowl habitat and provide new benefits to fish and other wildlife species that non-tidal seasonal wetlands may not currently provide. A related purpose is to provide waterfowl habitat that is reliable, resilient, and as self-sustaining as possible. Traditional waterfowl management systems in Suisun Marsh are based on flood-drain schedules to encourage the growth of waterfowl food plants. Techniques developed in the 1950s and 1960s are followed to decrease soil salinity and increase production of alkali bulrush, fathen, and brass buttons. Alkali bulrush was encouraged because it's tolerant to salinity and is considered to be a good duck food (Mall and Rollins 1972). Managers conduct leach cycles from the end of duck season until April or May to remove salts from the soils. During summer, pond bottoms remain dry to allow restrict growth of cattails and tules and to allow heavy equipment to be used to disk pond bottoms. The length of the leaching cycles is used to control the composition of vegetation.

Managers and biologists are now recognizing that traditional management strategies are becoming unsustainable. Maintaining extremely dry soil conditions throughout the summer on the cat clay soils that underlay much of the marsh can significantly alter soil and water chemistries (Heitmeyer et al 1989). Waterfowl biologists have also discovered that alkali bulrush seeds are poorly metabolized by waterfowl and interest in managing for invertebrates has increased (Heitmeyer et al 1989).

We propose that waterfowl-priority non-tidal seasonal wetlands can be re-engineered to increase compatibility with sensitive tidal marsh-dependent species and eliminate or reduce adverse management effects by adopting a microtidal wetland waterfowl management system. Microtidal managed wetlands will be designed to feature permanently flooded submerged aquatic vegetation (SAV) in shallow brackish impoundments with restricted tidal flows. Brackish impoundments and tidal shallows supporting extensive SAV beds, particularly sago pondweed (*Potamogeton pectinatus*) (Figure 1) and wigeongrass (*Ruppia maritima*) (Figure 2), are widely exploited or managed as high-value habitat for waterfowl such as mallards (*Anas platyrhynchos*), pintails (*Anas acuta*), and canvasbacks (*Aythya valisineria*) on the U.S. Atlantic and Gulf coasts (DeVoe and Baughman 1986; Kantrud 1990; Kantrud 1991).

## MICROTIDAL WETLAND ENVIRONMENTS

Microtidal wetlands include marshes and shallow open water areas in estuaries where tidal range (the vertical rise and fall of tides) is less than 2.0 meters, or where tidal flows are choked (significantly reduced tidal range) relative to their tidal source, such that shores behave essentially like those of non-tidal coasts (Davies 1980; Hill 1994; Rydberg and Wickbom 1996; Goals Project 1999). In brackish ponds, sheltered shallows, and slow-flowing channels, sago pondweed is one of the dominant native submerged aquatic plants. It tends to dominate especially where salinities are less than 14 ppt. (Kantrud 1990). Wigeongrass has a much wider range of salinity tolerance (Kantrud 1991), but also occurs in Suisun Marsh's brackish ponds and marsh pans (CalFlora 2001). Both occur naturally in the San Francisco Bay estuary, but are most abundant where sheltered, shallow water with low turbidity prevails and bottom sediments are seldom or never emergent intertidally (Goals Project 2000). Portions of microtidal brackish wetlands that are occasionally exposed intertidally develop emergent marsh, principally tules, bulrushes, and cattails (Kantrud 1990). Upper intertidal brackish marshes develop mixtures of saltgrass (*Distichlis spicata*), pickleweed (*Salicornia virginica*), baltic rush (*Juncus balticus*), *Jaumea spp.*, marsh gumplant (*Grindelia stricta*), western goldenrod (*Euthamia occidentalis*), *Aster spp.*, and other moderately salt-tolerant forbs (Goals Project 2000).

## ENGINEERED MICROTIDAL WETLAND CONCEPTUAL DESIGN

Microtidal managed wetlands will be designed to feature permanently flooded, submerged aquatic vegetation (SAV) in shallow brackish impoundments with restricted tidal flows. The conceptual design for a managed microtidal wetland system is shown in Figure 3. Each system will incorporate the following features:

- reconstructed low, wide levees designed for minimal maintenance and high multi-species habitat value;
- self-regulating tidegates to establish appropriate water depths, flows, and restricted tidal range within impoundments;
- extensive beds of native SAV of variable composition, principally sago pondweed with some wigeongrass and other species;
- confined emergent marsh (tule, bulrush, cattail) to provide local cover, habitat diversity, and wind-wave shelter zones;
- channels for circulation, shallow-draft navigation, and confinement of emergent marsh vegetation; and, amenities such as brood water stations, blinds, foot access, and shallow-draft boat launches.

The designs for individual sites may be adapted to local constraints or opportunities determined by project siting, road access, tidal source, and existing conditions of levees, ditches, relict tidal slough patterns, bed elevations, and soils. The features of microtidal managed wetlands are discussed in detail in the following sections.

### Submerged Aquatic Vegetation Beds

Submerged aquatic vegetation beds will be designed to support extensive, productive, resilient beds of native SAV of variable composition through climate driven salinity cycles. The emphasis will primarily be on sago pondweed, with wigeongrass dominating in years with more saline conditions. Both species have sustained high forage value for preferred Suisun waterfowl species.

The Suisun Marsh historically supported extensive beds of sago pondweed. Field notes of Willis L Jepson record sitings of large ponds filled with sago. "The *Potamogeton pectinatus* was floating everywhere on the surface of the ponds where the ducks had been feeding. [Sago] is the only thing in the ponds in the form of a pondweed, and the only aquatic seed-plant that I saw. It fills the ponds so densely that it is impossible to get a boat through." (Jepson 1904). Early (1900-1925) management of wetlands in Suisun

Marsh included permanently flooded ponds to encourage growth of SAV. The ponds were equipped with gates that continually circulated water through the ponds. These ponds contained abundant sago pondweed, water nymph and wigeongrass until carp (*Cyprinus carpio*) populations became excessive (Heitmeyer et al 1989).

Maximum availability of sago pondweed vegetation is likely to occur from March through August. In temperate climates, sago pondweed is one of the first submerged plants to begin spring growth, with plants reaching the water surface in May to mid-July (Kantrud 1990). SAV growth in the San Francisco Bay estuary is often observed earlier in spring (Baye 2001, personal observation; see “Notes”). About two weeks after growth begins, healthy stands can cover much of the water surface. Sago pondweed vegetation normally becomes senescent from late August to October. Sago pondweed vegetation dieback can occur when water salinity is greater than 15 ppt. This may occur as early as mid-July in Suisun Marsh in drier years. Drupelets, the starchy fruits of sago pondweed, begin germination from late March to early summer and are usually mature by late July to late September. Turions, the vegetative propagules, have peak development in late summer or early fall.

Wigeongrass develops similarly to sago pondweed but is more salt tolerant. Wigeongrass will likely be the dominant SAV in dry, more saline years. In North Dakota, sago pondweed is replaced by wigeongrass at salinities more than 26 g/L (Stewart and Kantrud 1972).

### **Emergent Vegetation**

Confined patterns and amounts of emergent marsh vegetation (tule, bulrush, cattail) will be established on shallow berms to create sheltered coves of variable size, provide cover, trap tidal sediment, and establish baffles to reduce wind-wave fetch. The berms (see Berms and Channels section below) will be confined by steep channels of variable depth (minimum of 1 meter) and width, which should prevent vegetative spread of tall emergents (Grace 1985).

Vegetation at low tidal marsh elevations within managed microtidal wetlands should be dominated by alkali bulrush in the more saline portions of the marsh; cattails and tules (*Typha angustifolia*, *T. latifolia*, *T. dominguensis*; *Scirpus californicus*, *S. acutus*) in the fresher portions of the marsh. The middle marsh zone should be dominated by saltgrass (*Distichlis spicata*) with other common species including pickleweed, fat hen, baltic rush, *Jaumea carnosa*, alkali heath (*Frankenia salina*) and dodder (*Cuscuta salina*); and may support some uncommon native plants. At high tidal marsh elevations, vegetation may include marsh gumplant, saltgrass, alkali heath, and robust tall growth forms of pickleweed.

### **Levees**

Microtidal wetlands are compatible with low, wide, gently sloping vegetated levees, which may be overtopped during storm surges (Figure \_). These intermittently flooded levees are designed to minimize artificial predator dispersal and denning; re-establish facsimiles of marsh topographic gradients, accommodate natural patterns of debris deposition and shoreline disturbance; and provide wave energy buffers. Levee slopes (at least interior slopes) will be widened to at least a 1:10 slope, with a flat bench or toe on the interior side, and revegetated with native sod-forming grasses, rushes, bulrushes, and tules, according to topographic position and flooding frequency. Creeping wildrye (*Leymus triticoides*) and saltgrass will be featured as principal sod-forming stabilizers to retard erosion; native terrestrial shrubs will be added to provide high tide escape habitat for resident native marsh wildlife. A zone of well-drained, briefly flooded, pickleweed-mixed vegetation on the wide interior levee slope should provide stable, high-value habitat for endangered salt marsh harvest mice with no water management conflicts with waterfowl habitats, and close proximity to flood escape habitat on vegetation of the upper levee slopes. The wide bench and toe of tule vegetation is designed to minimize internal erosion due to wind-waves of the flooded basin, although extensive beds of SAV should prevent significant wind-wave generation most of the year.

Allowing shallow periodic flooding of lower edges of levees will promote dense, tall, high marsh vegetation, which provides cover (tidal refugia) for resident native marsh wildlife. The expected dense vegetation will also reduce the efficiency of predator travel and foraging. Lower crest elevations will also

facilitate the dispersal of tidal litter, which is an important natural component of tidal refugial habitat (Johnston 1957). Intermittent overtopping by spring tides will flood out terrestrial predator dens (rats, raccoons, skunks, fox) where they are not compatible with local management priorities and endangered species recovery.

Lower levee crests and gentle, vegetated levee slopes should reduce levee erosion and eliminate maintenance requirements. Lower crests will subside at slower rates than levees capped at higher elevations. Elimination of the recurrent disturbance cycle associated with dike erosion and maintenance may reduce the competitive advantage of many non-native plants, and high marsh vegetation may eventually dominate.

### **Berms and Channels**

Where historic slough patterns can be reconstructed (through historic maps and analysis of residual channel topography), they may form the template for efficient microtidal circulation channel patterns. Excavated sediments from old creek beds will be deposited in low berms along creek levee alignments. Their crests will lie at or slightly above low tide elevations during microtidal wetland operation, providing nurseries for tule, bulrush, and cattail seedlings or transplants. A second track of deep, narrow channels will be excavated opposite the “tule nursery berms,” to provide a local deepwater barrier to their spread. Extensive SAV will restrict sedimentation in these outer subtidal ditches. Excavating main tidal circulation channels with irregular, branching, sinuous forms creates random elements to emergent marsh patterns. These naturally irregular patterns will provide diversity of sheltered coves and variable sizes of open water areas.

### **Water Management**

The microtidal wetlands would be designed to maintain sufficient restricted tidal flows to establish optimum water column depths for dabbling ducks, sago pondweed, wigeongrass, and high water quality (low turbidity, low nutrient levels, adequate oxygenation, nonextreme and nonharmful salinity fluctuations). Permanent shallow water habitat will be maintained with a system of water control structures. Inlet structures will likely consist of one or more culverts, each with a self-regulating tide gate. Float systems on these gates are adjusted to allow enough tidal flow to flush the ponds, but automatically close at a predetermined tide elevation. In deeply subsided locations it will likely be necessary to increase the artificial asymmetry between ebb and flood tidal flows, in favor of ebb drainage. The artificial asymmetry can be enhanced by separating flood and ebb flows (distinct outlets and inlets), and installing more ebb drainage capacity (more and larger flapgates) than flood inlet capacity (fewer and smaller flapgates). Size and number of culverts must be adjusted to the dimensions of the site and the local tidal hydrology. Engineered inlets and tidegates will be installed where existing structures are located or fringing outboard tidal marshes are narrowest. These locations should minimize marsh effects, and ensure the greatest access to unrestricted tidal flows with the least dredging and maintenance of intakes.

Water depth will be controlled to provide optimal growth of SAV and optimal waterfowl habitat while also providing habitat for other wildlife species such as shorebirds, wading birds and aquatic species. The management strategy will follow an adaptive management approach. The initial management strategy is based on waterfowl management strategies for brackish tidal wetlands developed by Ducks Unlimited, the South Carolina Department of Natural Resources, and other organizations.

Tidal range should be adjusted to submerge tule-cattail berm tops daily, and maintain permanently flooded conditions in SAV beds. An average tidal depth range of 60 cm to 1.0 m is proposed for SAV beds. Optimum growth of sago pondweed and wigeongrass in ponds with clay or silt bottoms occurs at water depths less than 1.5 m. At the Galilee Bird Sanctuary in Narragansett, Rhode Island large *Ruppia* beds were documented in a salt marsh receiving restricted tidal flows. Daily tidal ranges were 15-25 cm, and tide levels ranged between 0.3 m and 0.6 m. Nearly all of the ponds were subtidal (permanently flooded). *Ruppia* percent cover ranged from <5% in one pond to up to 74% in another (Myshrall et al. 2000).

Maximum tidal range that maintains at least 5 cm submergence of the SAV beds should provide optimal foraging potential for dabbling ducks at low tide, minimum potential for "dead zones" of poor local tidal

circulation (evaporative concentration of salts, low dissolved oxygen). Tidal range will likely be adjusted according to season. During waterfowl season, tidal range can be set to maximize the foraging area (depth of 18 inches or less) for dabbling ducks. During the warmer summer months, tidal range can be increased to prevent adverse water quality conditions and provide optimal habitat for aquatic resources. Topographic variability and sedimentation would provide substantial areas shallower and deeper than the average depth. Sediment accretion in the beds and channels should be monitored; tidal range can be reduced if sedimentation rates are too high. If sedimentation rates require low sustained levels of tidal circulation to maintain topographic controls, the basins should be flushed periodically (temporary full tidal range, at least monthly spring tides) to offset water quality problems.

### **Amenities**

In some locations, microtidal managed wetlands will provide access and recreational benefits to game hunters. Recreational amenities that may be used in individual designs include:

- hunting blinds;
- boat launches for shallow-draft boats; and
- brood water stations, consisting of small PVC storage tanks (reservoirs), pump-out pipes, and floating interior platforms with duckling accessible freshwater dispensers.

### **PROPOSED VEGETATION ESTABLISHMENT METHOD**

Although sago pondweed and wigeongrass readily colonize newly reflooded submerged sediments in favorable conditions (Kantrud 1990, 1991), factors such as excessive bottom sediment mobility, turbidity, and adverse sediment chemistry (e.g., acid sulfates, residual hypersalinity, extreme low redox) (Portnoy 1999) may impede colonization and establishment. Rapid colonization by emergent brackish marsh vegetation (cattails and tules) can also preclude establishment of persistent SAV. The following measures are proposed to address potential problems related to turbidity, excess internal wind-wave energy, bottom substrate stability, edaphic properties, and plant competition. Implementation of each of these phases would occur on a site by site basis. The initial condition of the site will dictate the length of each phase. Some sites may not require the phase 2 (see sections below) sediment deposition, while others may require prolonged phase 2 deposition.

#### **Phase 1. Emergent Revegetation Phase**

Phase I will restrict emergent plant seedlings by sustained shallow flooding of proposed SAV beds, allowing establishment of cattails and the tules only on the tops of emergent (future intertidal) berms. Cattails and tules have very small seeds and require emergent, exposed mud to establish seedlings. Although larger established seedlings of these species can subsequently tolerate submergence, seeds cannot germinate under water (Grace 1985). Before the first growing season, after grading of berms and channels is complete, the basin floor must therefore be at least shallowly flooded at all times. Exposure of mud ("drawdown" conditions) would provide emergent marsh seedling nursery conditions on what is proposed as SAV beds. This must be prevented by permanent flooding. During this period, the tidal range within the basin should be periodically increased to prevent evaporation and concentration of salts in shallowly flooded areas. These large tidal pulses should be timed, if possible, with low wind periods to minimize incident wind-wave energy on the relatively steep tule berms.

The "tule berms" tops in contrast should be subject to partial or complete temporary emergence and flooding to facilitate establishment of localized tule-cattail vegetation. Tule-cattail berms may also be sprigged at low densities with rhizome fragments (vegetative propagules) in winter or early spring to accelerate establishment. Deep, steep-sided channels (at least 1.5 meters wide) should check the lateral spread of tule-cattail rhizomes on berms. After the tops of tule-cattail berms are vegetated, they may also be shallowly flooded.

### **Phase 2. Substrate Preparation Phase**

Phase 2 will prepare the SAV substrate by deposition and consolidation of new sediment. Deposits of fresh estuarine sediment are designed to mantle the graded original surface of the diked bayland basin, providing a favorable substrate for establishment of SAV regardless of previous soil conditions. This procedure may be necessary for establishing SAV in “red water” pans from previous deteriorated (acid sulfate, hypersaline) soil conditions. Deposition of at least several centimeters of sediment should be sufficient for establishment of shallow SAV rhizome systems, which function principally as anchorage and vegetative propagation. Initial rapid deposition of a discrete layer of tidal sediment will require a phase in which deep flooding and maximal tidal circulation occur, in contrast with the design operation for established SAV. Deep flooding and maximal tidal range require measures to address excessive internal wave energy, which can favor resuspension of sediment rather than deposition, and may temporarily cause excessive erosion of berms and levees.

When tule-cattail berms (3.0 m wide) are mantled by dense, tall, emergent marsh vegetation, they should act as wave baffles (bottom roughness, which impedes propagation of wind-waves). Tall tule/cattail vegetation, unlike seedlings, can tolerate prolonged, relatively deep (> 1 m) flooding, since a significant portion of the foliage remains above the water level. Similarly, the lower portions of perimeter “habitat levees” should support wave-baffling dense, tall, emergent marsh. These features will reduce internal wave energy generation and stabilize gently sloping, dissipative marsh edges even during phases of relatively deep flooding (1.5 to 2.0 m). This phase may take as little as one full growing season or as much as two growing seasons.

Tidegates should be initially set to allow maximal tidal circulation to trap fine sediment in the sheltered beds around tule-cattail berms. The time required for sufficient sediment deposition is expected to vary with fluctuations in sediment availability and local sediment sources. It may occur in as little as one year (after establishment of tule berms), but may take as much as two years.

When approximately 75% of the basin floor has accreted at least 5 cm of fresh mud, the basin should be very briefly drained by closing tidegates during rising tides, but allowing ebb drainage. The newly deposited mud should be exposed to air for a few days to allow partial dewatering, consolidation, and shrinkage (time depending on air temperature and humidity), but should not continue long enough to result in significant drying and cracking of a hard surface, or allow seedling establishment of emergent plants. The purpose of the consolidation (partial dewatering) phase is to provide a mud surface that will provide some initial mechanical stability during initial reflooding, sufficient to promote establishment of SAV. Pre-consolidation of the surface will also help limit peak turbidity during initial reflooding, prior to establishment of SAV. Loose, freshly deposited gel-like bay mud is easily resuspended, and may be too loose for efficient colonization by SAV.

### **Phase 3. SAV Establishment Phase**

Some SAV may spontaneously establish in Phase 1, but efforts to establish it are not proposed until bed conditions are optimized. SAV should be established initially under conditions of very limited tidal circulation and shallow flooding early in the growing season, before peak filamentous algal growth periods, and during relatively low-salinity periods favorable to germination and establishment of seedlings and vegetative propagules. Low-energy conditions (weak currents, low tidal range, low wave energy in shallow water) should facilitate settling of SAV seeds and vegetative propagules, minimize turbidity, and minimize bottom disturbance.

Several methods of SAV propagation and establishment may be employed. Plugs (cores of firm sediment containing fragments of rhizomes and tubers) are expected to have high establishment rates if predation by waterfowl is not excessive, but plugs are more costly and labor-intensive than broadcast methods. If waterfowl predation of transplanted plugs is excessive, a few “caged” plugs (submerged poultry mesh covers) may be used to establish selected founder colonies. Plugs do have the advantage of establishing early in the growing season, soon after dispersal. Broadcast methods involve raking living SAV shoots from source areas during seed dispersal, and simply discharging them into target areas. Broadcast methods

may depend on seedling establishment, and may occur mostly in the growing season following sowing (Kantrud 1990, 1991). Some rooting and establishment of vegetative fragments may occur.

Once SAV beds are extensively established, the floating foliar canopy should strongly impede wave generation during the growing season. In combination with the tule-cattail berms, they should maintain sheltered, low-energy conditions in the shallowly flooded basin. The accumulation of submerged SAV biomass after seasonal dieback also maintains significant bottom roughness, and should also retard wave propagation. Rhizome system "fabrics" help bind and stabilize bottom substrate, minimizing resuspension of fine sediment.

### MICROTIDAL WETLAND MANAGEMENT BENEFITS

The MTW management system is anticipated to have multiple benefits. One of the principal benefits the system hopes to provide is sustainable high-quality waterfowl habitat that supports other wildlife species.

#### Benefits to Waterfowl

The microtidal wetland systems should provide habitat to support the same spectrum of avian species that utilize traditionally managed waterfowl wetlands. Abundant food sources in the form of SAV should attract preferred waterfowl species. Sago pondweed rates as one of the most valuable species of submerged aquatics for waterfowl. The importance of sago pondweed to staging and migrant waterfowl is so great that, at least in North America, continental migration pathways of some species can be determined by the location of large water bodies dominated by the plant (Kantrud 1990). McAtee (1917) termed sago pondweed "the best all round duck food in North America." Martin et al. (1951) ranked the plant food's value to waterfowl as "the outstanding species in this outstanding genus."

Historically, ducks in Suisun Marsh foraged extensively on sago pondweed. "[Sago] fills the ponds so densely that it is impossible to get a boat through...Now that the ducks have cleaned it out so well that we had no trouble going anywhere". "2000 canvasback ducks will clean the tubers [of sago] out of a pond in a night; the sound of them eating is like the guzzling of hogs" (Jepson 1904).

Waterfowl eat all parts of sago pondweed: turions, stems, leaves, and rootstocks. Dabbling ducks (*Anatini*) likely consume mostly drupelets. Rhizome fragments or nearly whole plants often appear on the surface after being discarded by waterfowl that feed on turions. Much of this material is readily eaten by dabbling ducks. Diving ducks, such as canvasbacks (*Aythya*), are able to exploit foods in bottom sediments, and probably prefer turions when feeding on sago pondweed (Kantrud 1990). Sago pondweed has been found to compose 50% or more of the diet of canvasbacks; 25% to 50% of the diet of mallards and redheads (*Aythya americana*); and between 10% to 25% of the diet of pintails, teal (*Anas crecca*), and scaup (*Aythya* spp.) (Martin et al. 1951). Sago pondweed provides an ample source of carbohydrates for waterfowl. Approximately 75% of sago pondweed's nutrient composition consists of nitrogen-free extract, a measure of digestible carbohydrates (Krapu and Reinecke 1992). Sago pondweed consumption benefits waterfowl in other ways. Sago pondweed drupelets serve as a grinding media in waterfowl gizzards (Wetmore 1921), and sago pondweed can reduce the toxic effects of led pellets (Jordan and Bellrose 1951).

Sago pondweed beds are heavily used feeding sites for waterfowl broods due to the abundant and easily obtainable populations of macroinvertebrates, which are a prime source of protein for young birds (Hochbaum 1944; Monda and Ratti 1988). Studies have found extremely large invertebrate populations in sago pondweed beds, including diptera, trichoptera, odonata, chironomidae, and crustacea. (Kantrud 1990). Sago pondweed communities provide escape cover for macroinvertebrates, thus allowing them to thrive in the presence of small fish. Some studies have found sago pondweed to be poorly to moderately attractive to invertebrates. However, this was primarily in moving-water environments or open water areas free of emergent plants.

Wigeongrass serves a similar role as sago pondweed in its importance as a food source for waterfowl. “Wigeongrass like it’s relative sago pondweed, rates as one of the most valuable species of submerged aquatics in the whole country” (Martin et al. 1951). In the early 1900’s McAtee (1915) noted that “bays that have kept their wigeon-grass have kept their ducks; those in which the plant has been destroyed...have lost them”. Wigeongrass is especially valuable to waterfowl because it thrives in alkaline or saline environments that are unfavorable to most plants. In addition, waterfowl consume all parts of the plant: drupelets, branches, leaves, and rootstalks. Wigeongrass is primarily a food of dabbling ducks and diving ducks. In South Carolina and other areas in the eastern U.S., waterfowl managers follow various water management techniques targeting growth of wigeongrass. In South Carolina, wintering green-winged teals, northern pintails, and American wigeons intensively use communities where *Ruppia maritima* [wigeongrass] and *Eleocharis parvula* co-dominate (Kantrud 1991). Euliss (1989) noted that in irrigation wastewater evaporation ponds in California, American wigeons and redheads eat and uproot wigeongrass vegetation in deeper openwater areas; northern pintails then feed mostly on drupelets from the plants that was ashore. Martin et al. (1951) found wigeongrass composed 10% to 25% of the diet of redheads, and scaup; 5% to 10% of the diet of pintails and ruddy ducks (*Oxyura jamaicensis*); and 2% to 5% of the diet of mallards, canvasback, and green-winged teal.

The invertebrate community associated with wigeongrass is an important food source for many breeding and wintering birds. Wigeongrass provides cover for many estuarine and marine invertebrates (Kantrud 1991). Verhoeven (1980) found invertebrates associated with wigeongrass-dominated communities in western Europe number up to 43,800 m<sup>2</sup> with biomasses of up to 22.9 g/m<sup>2</sup> ash-free dry weight. Morgan (1954) commented on the large numbers of invertebrate waterfowl foods found in an Australian wetland dominated by wigeongrass and sago pondweed.

Localized supplemental freshwater sources could be provided in years of relatively high wetland salinity to improve mallard breeding success. This is based on research on mallard breeding in interior western states with saline marshes, where localized freshwater sources appear to be selected and exploited by mallard broods to avoid toxic effects of excessively saline environments for ducklings (Duebbert et al. 1983; Swanson et al. 1984).

In addition to SAV, the microtidal wetland system will include shallow berms of emergent marsh vegetation, such as alkali bulrush, to create sheltered coves of variable size, provide cover, and provide an additional food source.

### **Benefits to Estuarine Habitat**

Microtidal wetlands, which supply shallow, subtidal estuarine beds of SAV should provide habitat for a wide range of native estuarine species. Connection to the tidal cycle will allow fish to enter and exit the SAV beds; therefore, the fish should not be permanently entrained in the system. Configuration of the microtidal wetland circulation channels is similar to that of smaller first order channels in Suisun Marsh, which are used extensively by native fishes, including delta smelt (Peter Moyle, personal communication; see notes). Therefore, there is a high likelihood that the microtidal wetland channels will provide habitat that is attractive to native fish species. The high invertebrate numbers associated with sago pondweed and wigeongrass will likely provide a rich food source for estuarine fish species. Additionally, studies have found that the marsh surface is an important foraging area for fishes. In a study of a San Diego marsh fish with marsh access consumed six times as much food as fishes restricted to creek habitats (West and Zedler 2000).

In late summer, limited circulation within portions of the microtidal impoundments could at times become conducive to local hypoxia, hypersalinity, and excessive algal growth. These adverse water quality conditions can occur in some brackish estuaries with restricted tidal flows (Kuo and Neilson 1987; Portnoy 1991). Summer hypoxia and hypersalinity can be prevented in managed microtidal conditions by adjusting tidesgates during critical seasonal periods to increase tidal range, flows, and turnover of impounder waters. Hydrodynamic modelling and water quality monitoring will be utilized in project design and implementation to prevent adverse water quality conditions for fish and maintain suitable subtidal vegetated shallows as habitat for native estuarine fish.

### Benefits to Other Wildlife

Microtidal wetlands should provide habitat for a wide variety of native marsh species. The SAV could provide an abundant food source for a diversity of waterbirds in addition to waterfowl. In South Carolina wigeongrass impoundments, shorebirds accounted for 53% of the average annual use of the managed units, while waders accounted for 14% of the use. Patterns of shorebird use were directly related to feeding and resting behaviors as well as water level management (DeVoe et al. 1986). Bourn and Cottam (1950) indicated that wigeongrass was a minor food of various rails (*Rallus* spp.), yellowlegs (*Tringa* spp.) and willets (*Catoptrophorus semipalmatus*). Martin et al. (1951) reported use of sago by avocets, dowitchers, godwits, and sandpipers. Sago seeds accounted for up to 10% to 25% of the diet of avocets and 25% to 50% of the diet of godwits. Waterfowl use of the SAV will be strongly influenced by water depth. Shorebirds typically forage in tidal mud flats and fringe marsh at depths below 2.5 cm. Variations in SAV bed topography may allow for areas at this depth.

In addition to waterbirds, microtidal wetlands should provide habitat to mammals such as the salt marsh harvest mouse. The SMHM, a small native rodent endemic to the salt marshes and adjacent diked wetlands adjacent to San Francisco Bay, is a State and federally listed endangered species. The preferred habitats for SMHM are the middle and upper portions of salt marshes, i.e., the pickleweed (*Salicornia virginica*) and peripheral halophyte zones, and similar vegetation in diked wetlands (Goals Project 2000). Microtidal wetland management would support middle and high brackish marsh vegetation that is protected from prolonged flooding and maintenance activities associated with non-tidal seasonal wetland management.

### Management Benefits

Microtidal wetland management should provide multiple benefits to managers. This management strategy should reduce some of the adverse effects of traditional management (soil hypersalinity, soil acidification, subsidence). In addition, microtidal wetland management should require less maintenance resulting in less management costs.

### Soils

In natural conditions, marsh soils are waterlogged and anaerobic. Traditional wetland management strategies include complete drying of the pond bottoms during the summer months. Complete drying of these soils causes accelerated decomposition of marsh litter, subsidence, oxidation of soils, and drastically lowered pH (Heitmeyer et al 1989). When alkaline waters inundate these low pH soils, dissolved iron becomes suspended and eventually precipitates as ferric hydroxide, causing “red water”. These conditions are toxic to some plants and invertebrates.

The SAV beds will be permanently waterlogged and anaerobic. The goal is to approximate soil conditions existing in natural lower tidal marshes and depression pans, which are frequently immersed throughout the year. These soils have relatively constant salinity that rarely exceeds that of the flooding water (Adam 1990). At higher elevations, such as along the levee slopes, soil salinity will likely be more variable. During drier periods, evapotranspiration will increase soil salinity. Between periods of tidal flooding, rainfall will reduce soil salinity (Adam 1990).

Microtidal wetland management should stop or reverse soil subsidence. Subsidence is primarily caused by decomposition of organic matter in soils. In natural conditions, where marsh soils are waterlogged and anaerobic, organic carbon accumulates faster than it can decompose. Diking and draining of marsh soils leads to aerobic conditions that favor rapid microbial decomposition of the carbon in the peat soil (USGS 2000). Microtidal wetland management will return the soils to waterlogged, anaerobic conditions that should stop the decomposition of the peat soils.

Studies in Connecticut comparing tidally isolated marshes with tidally influenced marshes found that isolated marshes were lower in elevation relative to tidal marshes. Lowering of the water table, with drying out of the marsh peat and subsequent compaction, may contribute to the lower elevation. Also increased

microbial populations, better adapted to the drier and less saline environment, may be acting to accelerate the decomposition of peat underlying the litter (Roman et al. 1984).

Microtidal SAV beds and brackish marsh vegetation are expected to trap most tidal sediment transported through constricted tidegates, channels, and ditches. The rate of sedimentation would be constricted proportionally with reduced tidal range, and dispersal of sediments within the microtidal wetlands would be further restricted by SAV bed roughness, tule berm barriers, and low-velocity tidal currents within the impounded shallows. Overall rates of tidal sedimentation within the microtidal managed wetland would probably be significantly lower than comparable full-tidal conditions, but significantly greater than conventional non-tidal Suisun Marsh management.

### Salinity

Management of soil and water salinity is one of the principal goals of traditional seasonal wetland management. As the ability to drain efficiently declines with increasing subsidence in non-tidal managed marshes and rise in sea level, this goal becomes increasingly difficult. In addition, maintenance of desired salinity levels requires tight water control and an inflexibility to manage with variable water salinity. Microtidal wetlands should be tolerant of salinity variability because sago pondweed grows actively up to about 14 ppt (Kantrud 1990) and wigeongrass maintains optimum growth up to 22 ppt. (Kantrud 1991).

Unlike seasonal wetland management, microtidal SAV beds have limited ability to hyperaccumulate salts because of their persistent choked tidal circulation. Instead, they are likely to exhibit moderate lags and peaks in salinity variation, becoming fresher longer in spring and slightly more saline in summer/fall as compared with adjoining estuary conditions. The lags and exaggerated salinity variation of microtidal SAV beds are due to their turnover rates, which are intermediate between non-tidal ponds and full tidal wetlands. The SAV beds tend to accumulate fresh water from direct rainfall and winter tides during periods of depressed estuarine salinity, and maintain significantly lower brackish salinities later into spring than adjacent tidal marshes in average to high rainfall years (Baye 2001 personal observation; see “Notes”). Conversely, in late summer the SAV beds may develop salinity somewhat greater than adjacent tidal water because of the evaporation pan effect, particularly during neap tidal phases. By modifying the timing and degree of tidal circulation, the salinity of microtidal SAV beds should be adjusted seasonally to some degree, and extremes of salinity can be avoided at all times.

### Minimization of Repair and Maintenance

Dikes and water control structures of traditional non-tidal waterfowl wetlands were designed for a routine maintenance program and a high degree of hydrologic isolation from tidal influence. This design requires relatively high, steep dikes and close control of water transfers. Microtidal wetlands in contrast, can be designed to relax the need for tidal isolation and the precision of water control of dike-enclosed basins, with structures which are tolerant of tidal overtopping and less prone to rapid deterioration. This resilience allows for lower, flatter-sloped dikes with dense vegetation (habitat levees) which are subject to intermittent flooding. Erosion resistance of reconstructed dikes (low-angle slopes and vegetative stabilization) should be emphasized.

## **UNCERTAINTIES TO BE ADDRESSED**

Below we identify some gaps in our understanding of how a microtidal wetland waterfowl system will function, how it will meet the habitat needs of wildlife, and how to more effectively communicate our knowledge to landowners and managers.

- Can water control structures create a muted tidal system and allow manipulation of residence time and water depth?
- Can SAV beds be propagated in a muted tidal system with varying water depths?
- Will SAV provide equivalent waterfowl habitat (forage, cover, nesting) as compared to non-tidal management systems?

- Will SAV beds and circulation channels provide food and cover for native aquatic species? Will they favor natives or non-natives?
- How can we communicate the need to develop a more sustainable waterfowl management strategy to landowners managers?
- Will landowners be willing to convert to an alternative waterfowl management strategy?

### **RECOMMENDATIONS**

Our recommendation is to conduct a set of demonstration projects to evaluate the effectiveness of a muted tidal wetland waterfowl management strategy. Ideally, three individual sites should be selected to encompass a range of SAV bed elevations and water salinities, and cover different geographic locations throughout the marsh.

Criteria to be evaluated for site selection include:

- proximity to tidal source;
- SAV bed elevation;
- size of parcel;
- condition of existing levee;
- condition of existing habitat;
- length of levee between adjacent property(ies); and
- presence of threatened and/or endangered species or their habitat.

Preferred sites would have (1) minimal conflicts with existing biological resource values (few endangered species effects, moderate to low quality waterfowl habitat); (2) high potential for habitat improvement (substantial physical deterioration in one or more aspects, such as soil acidity, hypersalinity, poor drainage, excessive subsidence) and (3) narrow “necks” in levee configuration, so isolation from adjacent non-tidal wetlands will not require excessive new levee construction or only minor levee upgrading. Adequate access for construction equipment and materials by road or barge will be highly advantageous.

### **ACKNOWLEDGEMENTS**

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## NOTES

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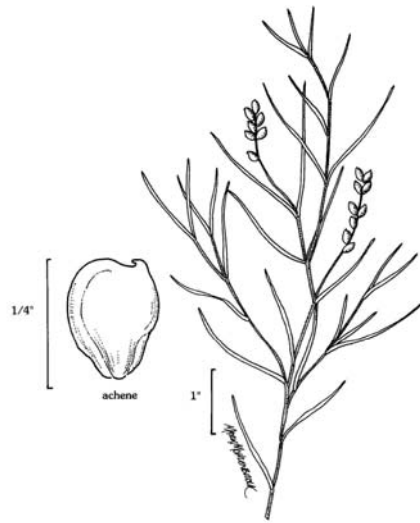


Figure 1. Sago Pondweed (*Potamogeton pectinatus*)

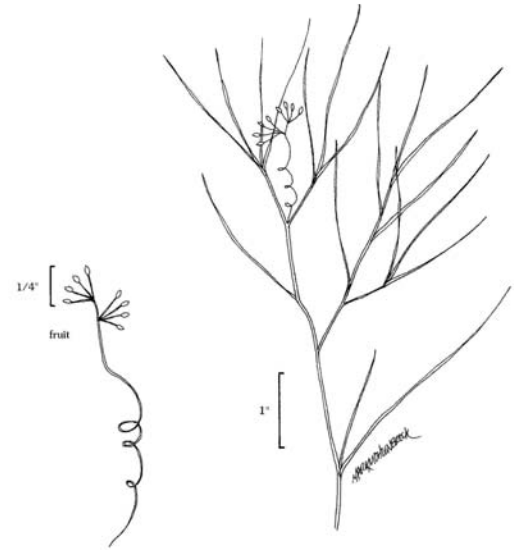
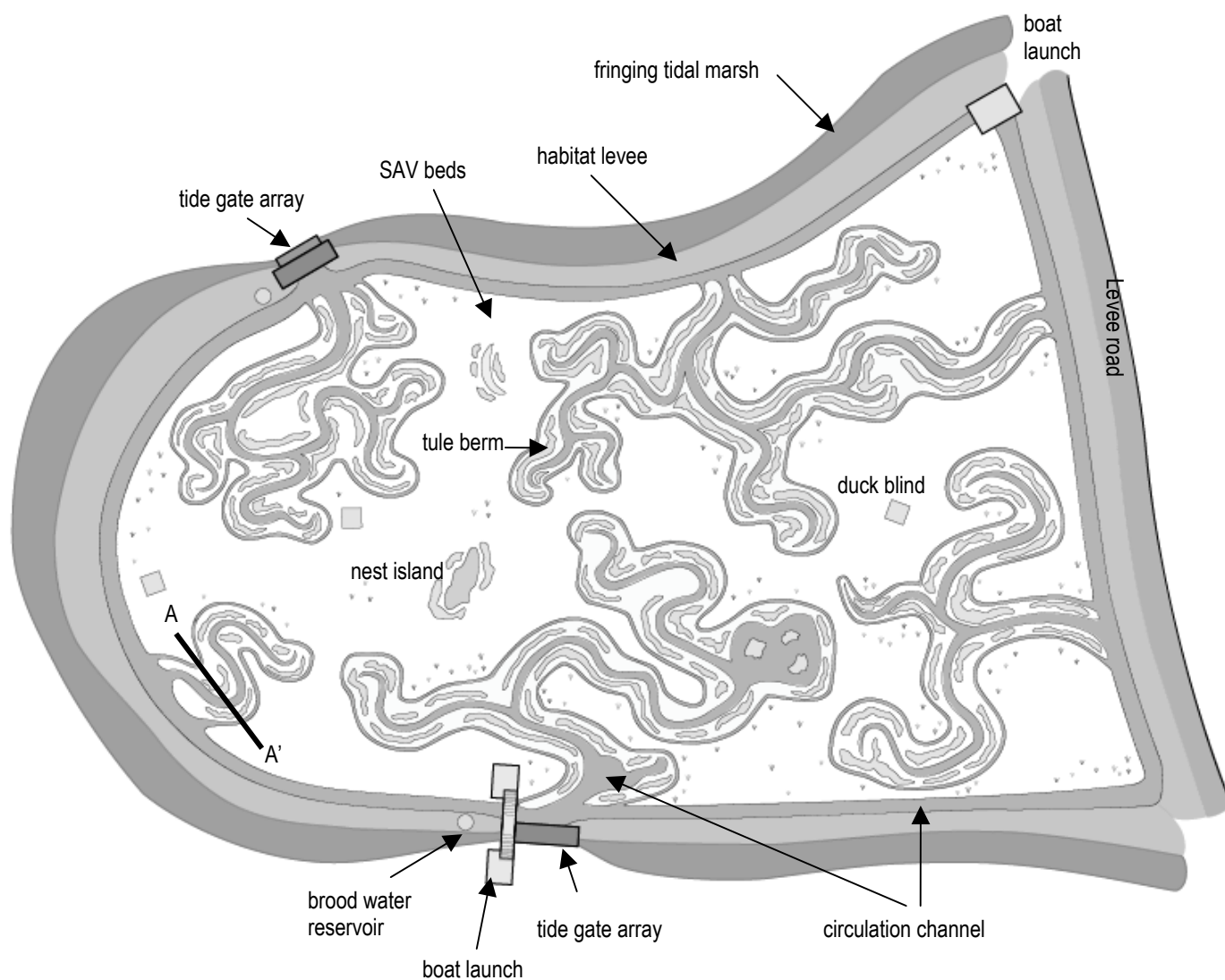


Figure 2. Wigeongrass (*Ruppia maritima*)



#### Section A-A'

Note that the dimensions will vary based on conditions present at a particular site. Widths and depths shown here are approximate.

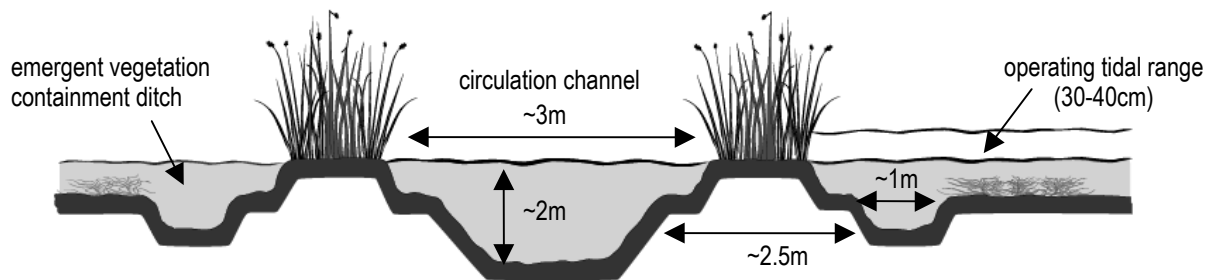


Figure 3. Conceptual design of a microtidal wetland